OHIO RIVER BASIN PRECIPITATION FREQUENCY PROJECT

Update of *Technical Paper No. 40, NWS HYDRO-35* and *Technical Paper No. 49*

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1. Introduction

The Hydrometeorological Design Studies Center (HDSC), Hydrology Laboratory, Office of Hydrologic Development, U.S. National Weather Service has updated its precipitation frequency estimates for the Ohio River Basin and surrounding states. Previous precipitation frequency estimates for this area were contained in *Technical Paper No. 40* "Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years" (Hershfield, 1961), *NWS HYDRO-35* "Five- to 60-minute precipitation frequency for the eastern and central United States" (Frederick et al., 1977) and *Technical Paper No. 49* "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller et al., 1964). The new project included collecting data and performing quality control, compiling and formatting datasets for analyses, selecting applicable frequency distributions and fitting techniques, analyzing data, mapping and preparing reports and other documentation.

The project determined annual all-season precipitation frequencies for durations from 5 minutes to 60 days, for average recurrence intervals from 2 to 1,000 years. The project reviewed and processed all appropriate rainfall data for the project area and used accepted statistical methods. The project results are published as Volume 2 of NOAA Atlas 14 on the Internet (http://www.nws.noaa.gov/ohd/hdsc) with the additional ability to download digital files.

The project produced estimates for 13 states. Parts of nine additional bordering states were included in the original analysis to ensure continuity across state borders. The core and border areas and regional groups used for long duration (24-hour through 60-day) analyses are shown in Figure 1. Regional groups used for short duration (60-minute through 12-hour) analyses are shown in Figure 2.

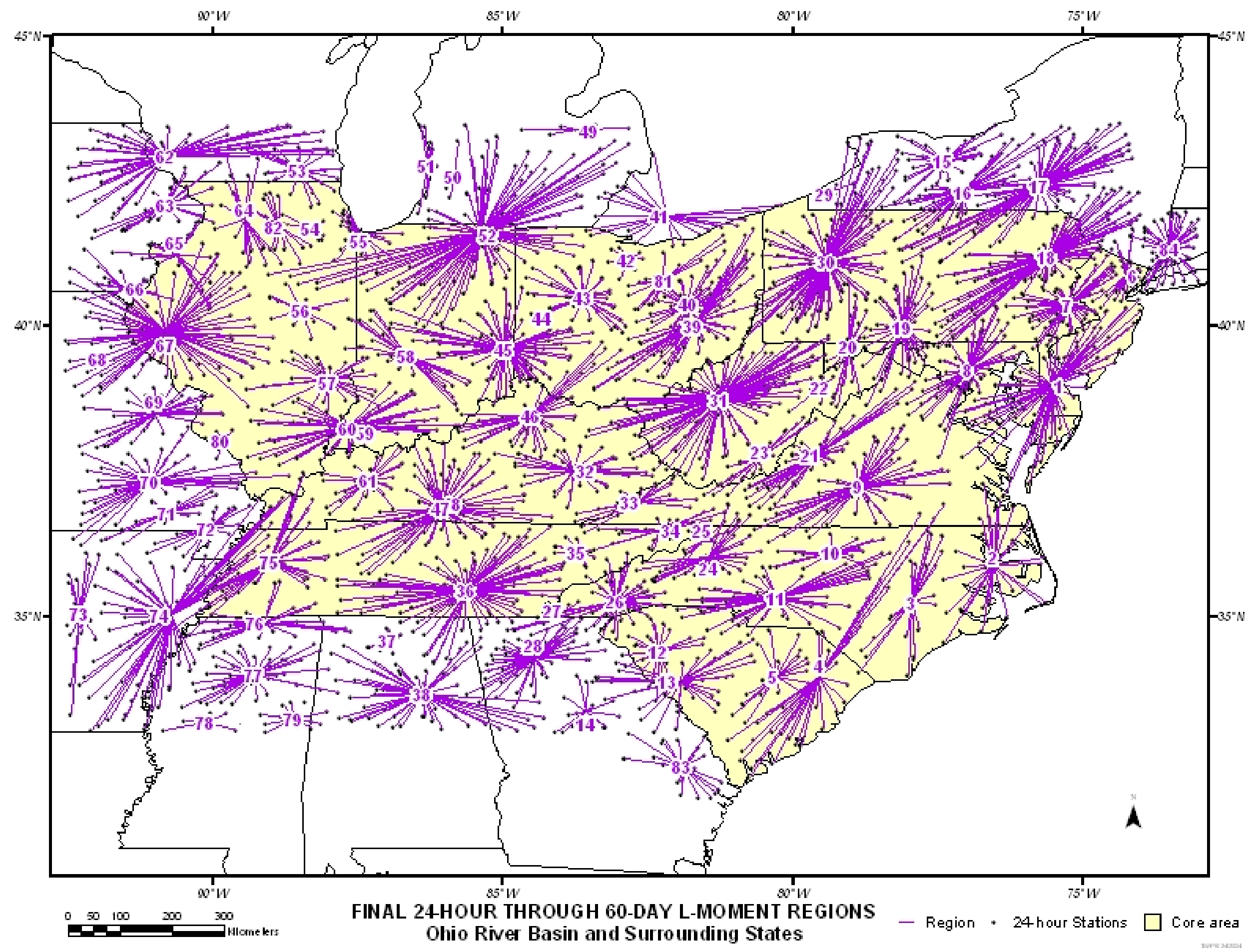


Figure 1. Ohio River Basin project area and 84 daily regional groups.

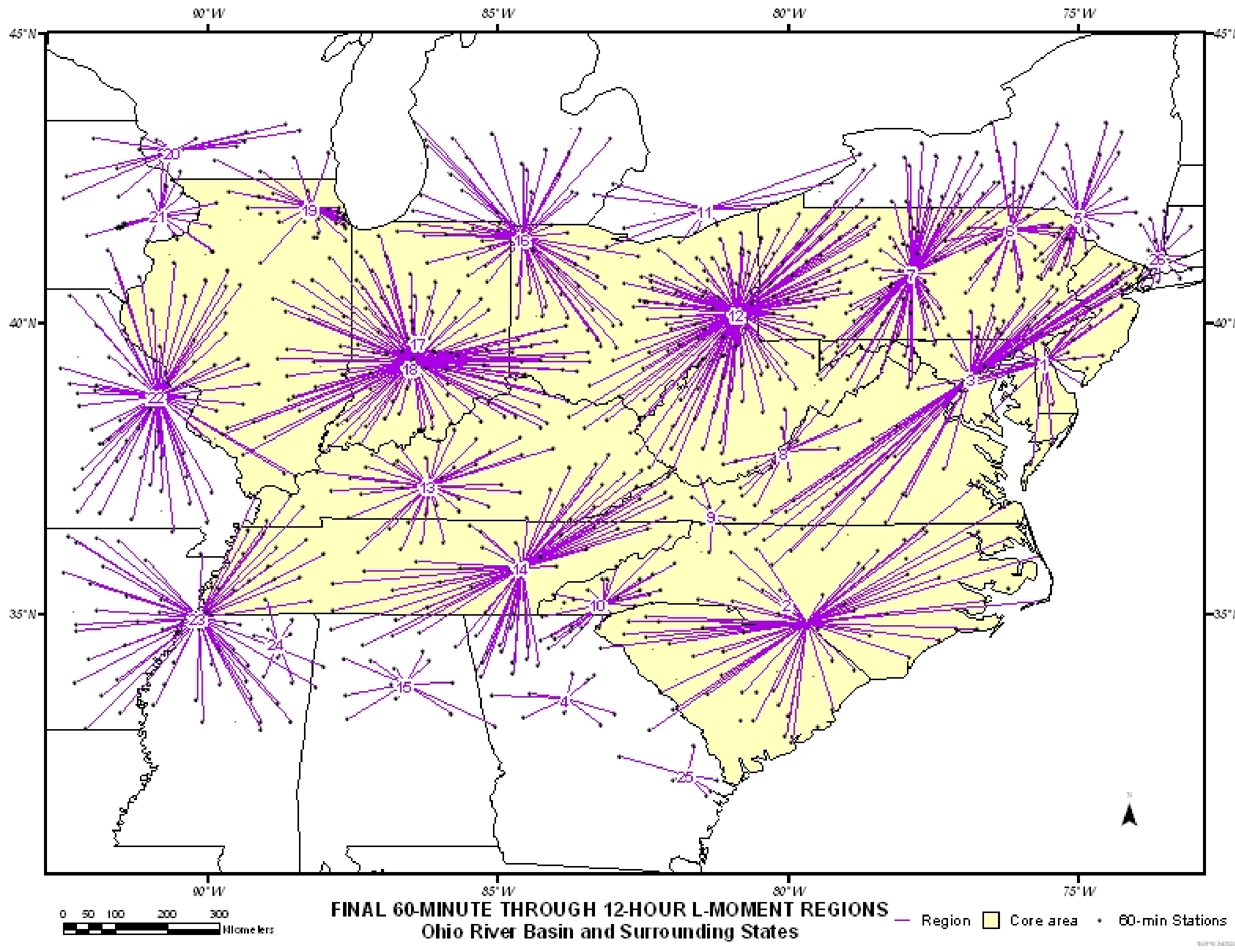


Figure 2. Ohio River Basin project area and 26 hourly regional groups.

2. Highlights

NWS published NOAA Atlas 14 Volume 2 precipitation frequency estimates for the Ohio River Basin and surrounding states on June 29th, 2004. They were made available via the Precipitation Frequency Data Server at http://www.nws.noaa.gov/ohd/hdsc.

A lack of data in some areas bordering the core area, specifically along the southwest border of South Carolina and the northeast border of New Jersey was noted. Data was added, quality controlled and analyzed to add information and offer continuity across borders. Additional information is provided in Section 3.1, Data Collection and Quality Control.

Sensitivity testing of probability distribution functions at long durations verified that the distributions that were selected based on the 24-hour analysis were appropriate for longer durations. During this check, it was observed that daily region 18 had inconsistencies in the number of 1,000-year real-data-check cases (RDCs). It was investigated and its distribution changed from GEV to GLO. Additional information is provided in Section 3.2, Distribution Selection.

Some potential inconsistencies/artifacts could not be examined until the final stages of the analysis process after all adjustments, spatial interpolation and smoothing techniques were applied. A detailed examination of the final results on a case by case basis led to corrections that have produced the best estimates possible. Modifications were made in seven cases. Additional information is provided in Section 3.3, Final Review and Modifications.

Precipitation frequency results were calculated using annual maximum series (AMS) data. Conversion factors from AMS to partial duration series (PDS) results have been calculated and applied to the results. Additional information is provided in Section 3.4, AMS-PDS Conversion Factors.

Hourly confidence limit software was modified to accommodate recent changes that ensure consistency between hourly-only stations and nearby co-located hourly/daily stations and thereby reduce bull's eyes in the hourly results. Software that adjusts quantiles for the co-location of daily and hourly data was modified to identify cases where the ratios of daily region 100-year 24-hour RGF versus hourly region 100-year 24-hour RGF were less than 1.0 and creating inconsistencies in precipitation frequency curves at the 60-minute duration. Additional information is provided in Section 3.5, Software Updates

SCAS delivered the final grids (Table 2) to HDSC on May 24, 2004. The Cascade Residual Add-back (CRAB) grid derivation process was used to create the entire suite of precipitation frequency grids for evaluation. During this process, it was determined that results were too low in/around the Chesapeake Bay and so mitigation measures were taken. For producing spatially smooth results, an advanced spatial smoothing algorithm was developed to mitigate climatologically unnatural variability in the spatially distributed precipitation frequency estimates. The algorithm smoothes estimates in areas with flat terrain and similar climates, but retains patterns in complex terrain or coastal areas. Also, a sub-routine was written to generate n-minute ratio grids for the two n-minute regions in the Ohio project area, northern and southern. In a subsequent sub-routine, these grids are multiplied by the appropriate 60-minute grid to create the n-minute precipitation frequency grids. Finally, in order to create climatologically sound short duration (<24-hour) precipitation frequency patterns in data void/limited areas, pseudo hourly stations were added to the mapping dataset at existing daily-only stations. Additional information is provided in Section 3.6, Spatial Interpolation.

The Precipitation Frequency Data Server (PFDS) under went several important changes to include new terminology and seasonal graphs. On June 29, 2004, the PFDS was populated with the final Ohio River Basin and Surrounding States precipitation frequency estimates. Not only were final point estimates made available via the point-and-click interface, but also the ArcInfo ASCII grids, shapefiles, and all associated metadata. Additional information is provided in Section 3.7, PFDS.

All study areas for the areal reduction factor (ARF) development have been selected have been quality controlled. A new site, Clark County, NV, has been identified and will be shortly added to the list of sites to be used in the A-R-F curve development. There are currently 14 sites located throughout the conterminous US, Hawaii, and Puerto Rico that have been quality controlled, processed and ready for ARF analysis. Software development to process the data and ultimately generate the ARF curves is still underway. Additional information is provided in Section 3.8, Areal Reduction Factors.

3. Progress in this Reporting Period

NWS published NOAA Atlas 14 Volume 2 precipitation frequency estimates for the Ohio River Basin and surrounding states on June 29th, 2004. They can be found via the precipitation frequency data server at http://www.nws.noaa.gov/hdsc/pfds. Point estimates (via the point-and-click interface), ArcInfo ASCII grids, shapefiles, and all associated metadata are currently available. Cartographic maps and final documentation will follow shortly.

3.1 Data Collection and Quality Control

A lack of data in some areas bordering the core area, specifically along the southwest border of South Carolina and the northeast border of New Jersey was noted. Data was added, quality controlled and analyzed to add information and offer continuity across borders. For the southwest border of SC, 17 daily and 7 hourly stations were added in Georgia as daily region 83 and hourly region 25. For the northeast border of NJ, 44 daily and 22 hourly stations were added in New York and Connecticut as daily region 84 and hourly region 26.

3.2 Distribution Selection

Sensitivity testing of probability distribution functions at long durations verified that the distributions that were selected based on the 24-hour analysis were appropriate for longer durations. During this check, it was observed that daily region 18 had a sharp increase in 1,000-year real-data-check cases (RDCs), where the maximum observation at a station exceeds its 1,000-year precipitation frequency estimate. A certain number of exceedences are expected statistically, however, the observed number of exceedences in daily region 18 increased from 3 to 12 between the 4-day to 7-day durations. Testing indicated that the generalized logistic (GLO) distribution was more appropriate for all durations in region 18. In sensitivity testing of the 24-hour duration, there was a <5% change in 100-year 24-hour estimates compared to the previously selected generalized extreme value (GEV) distribution. Climatological considerations also suggested that GLO was appropriate since there is some evidence that the topography in region 18 (southeastern Pennsylvania) may lead to an enhancement of hurricanes given the orography (elevation and aspect) of the area compared to surrounding areas. Indeed, hurricane and tropical storms contributed to the highest observed maximums in the area.

3.3 Final Review and Modifications

Some potential inconsistencies/artifacts could not be examined until the final stages of the analysis process after all adjustments, spatial interpolation and smoothing techniques were applied. HDSC carefully reviewed all pertinent spatially interpolated maps, particularly the 1,000-year, for spatial artifacts or unreasonable spatial patterns. Final precipitation frequency curves of stations were also screened using software for discontinuities in the slope of the curve beyond what was expected or reasonable. Such a review was critical for identifying and resolving any potential artifacts or discontinuities in regions or at stations that may be due to the process, particularly given the great number of stations in the project. This detailed examination of the final results on a case by case basis led to corrections that have optimized the results.

Case 1. The hourly regionalization along the east coast, particularly in North Carolina and South Carolina, was re-assessed because the 60-minute spatial pattern was not spatially cohesive and climatologically reasonable. This area was formerly comprised of two regions (hourly regions 2 and 4). Regional differences between these two regions were generating bull's eyes at adjacent stations. After a thorough investigation, it was decided to merge hourly regions 2 and 4. This smoothed the results in the area creating a more climatologically sound pattern consistent with expectations.

Case 2. A study of Aurora, IL was conducted and new regions created to mitigate low estimates in the area. Aurora, IL (11-0338; 111 years of data) has had two 24-hour events that exceeded the 100-year estimate (one of which exceeded the 1,000-year estimate). To retain potential storm information in this area, it was decided to subdivide daily region 54 into region 54 and region 82. As a result, 100-year 24-hour estimates in region 54 decreased by 5.1%. In region 82, which includes Aurora, 100-year 24-hour estimates increased by 21.5%. This is consistent with suggestions from reviewers regarding the spatial pattern in this area.

Case 3. Daily region 40 in Ohio was inspected and revised to create a more regular spatial pattern. It was identified because it contributed to an area of higher precipitation estimates in the 1,000-year 24-hour map. However, at the 100-year return frequency, it was spatially consistent. The probability distribution selected for this region was GLO for all durations, which tends to have a higher tail that produced the elevated 1,000-year estimates. A similar situation existed at nearby regions 42 and 44. Careful examination and sensitivity testing of all durations showed that GEV is also appropriate for all durations and generated more spatially consistent results. All but one of the 1,000-year RDCs that resulted with this change in distribution were less than their 1,000-year upper confidence limit. Therefore, GEV was used for the analysis of daily regions 40, 42, and 44. Daily regions 12 and 14, were inspected also, but found to be appropriately designated as GLO for all durations and climatologically reasonable.

In addition, the spatial pattern of region 40 was smoothed by adding 8 daily and 2 hourly stations from region 39 and 3 daily and 2 hourly stations from region 81. This resulted in a <5% decrease in 100-year 24-hour the quantiles in region 40, a <1% decrease in the quantiles of region 39, and a <1% change (both positive and negative depending on return frequency) in the quantiles of region 81.

Case 4. The pattern of the 1,000-year precipitation frequency curve at the daily-only station, Brandywine, WV (46-1091), suggested that more investigation was needed. Figure 3 shows the original PFDS output for Brandywine. The spatial interpolation process for the 12-hour duration was elevating the *interpolated* 1,000-year 12-hour estimate at Brandywine above its *calculated* 1,000-year 24-hour estimate creating an internal consistency violation that was caught by screening software. When this occurs, the spatial interpolation process will increase the subsequent durations by 1% until the calculated estimate at a given duration is greater than the spatially interpolated estimate. This created an artifact in the 1,000-year precipitation frequency curve as a flat “plateau” from 12-hour through 10-day. This situation also occurred at other daily-only stations south of Brandywine, but to a lesser extent. The 100-year 24-hour estimate at Brandywine was relatively low compared with nearby stations. And since Brandywine occurred at the boundary of daily regions 20 and 23 and of hourly regions 7 and 8, it was moved from daily region 23 to region 20 to mitigate the 100-year 24-hour estimate. Nearby regions 20 and 22 used the GLO distribution for their analysis, which enhanced the differences between the other regions, particularly at the 1,000-year. After a thorough investigation including sensitivity testing and consideration of consistency in the area, the generalized extreme value (GEV) distribution was used in regions 20 and 22, rather than the GLO distribution. The final results at Brandywine were checked for any 1% adjustments applied to the estimates during the spatial interpolation process. The current results, Figure 4, accurately represent the daily data with no spatially-interpolated artifact and are consistent with climatology in the area.

Figure 3: Example of artifact at Brandywine, WV caused by internal consistency issues between spatially interpolated results and calculated results.

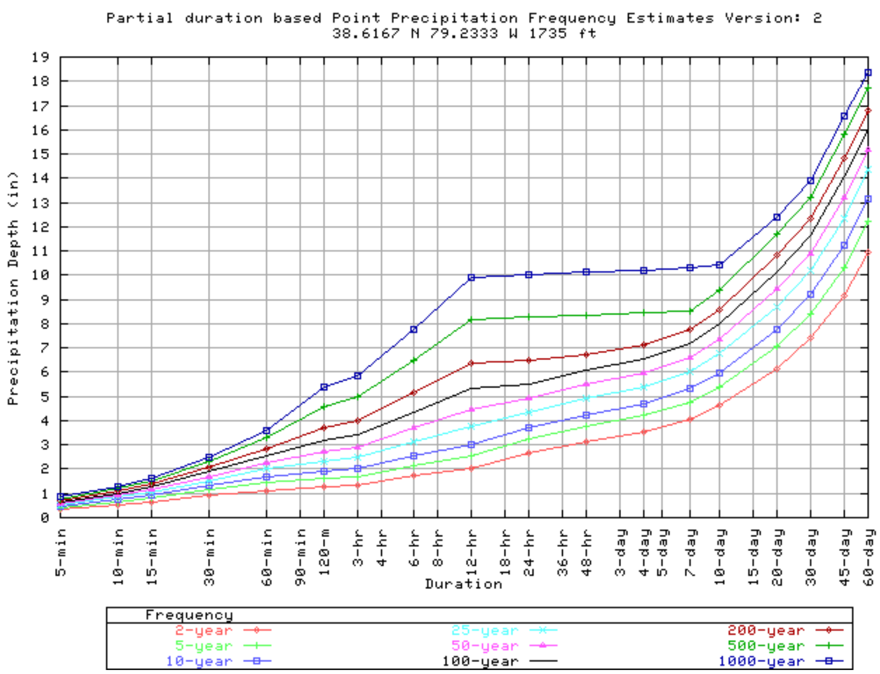
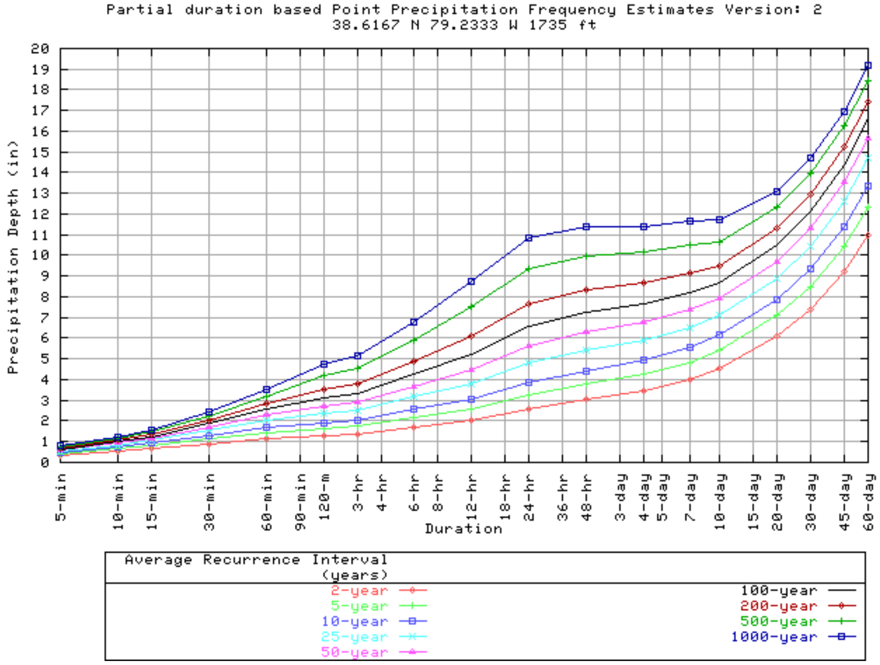
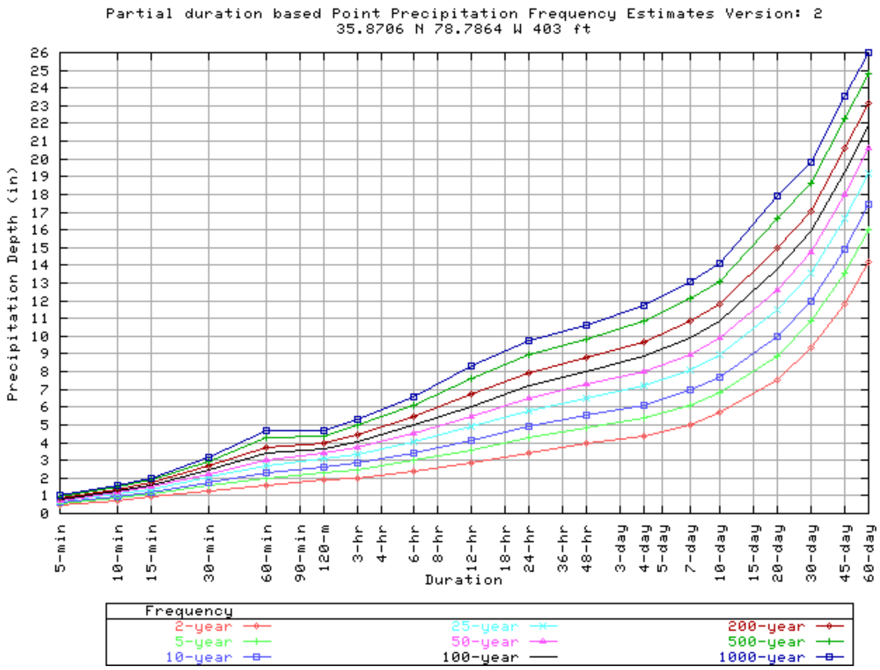


Figure 4: Final results at Brandywine, WV after mitigation measures to eliminate artifact.



Case 5. Discontinuities in slope of the 1,000-year curve between 30-minute to 60-minute and 60-minute to 120-minute were greater than what is typical of the Ohio Project (i.e., exceeded an established threshold) at 13 stations. Figure 5 shows an example where this occurred, Raleigh Durham WSFO AP, NC (31-7069). Research showed that these stations were special cases of co-located daily and hourly stations where the adjustments were insufficient due to the different characteristics of the daily and hourly regions in which they reside. These stations were adjusted by decreasing the 24-hour through 2-hour quantiles and increasing 60-minute quantiles leading to the discontinuity.

Figure 5: Example (Raleigh Durham WSFO AP, NC, 31-7069) of slope discontinuity between 30-minute to 60-minute and 60-minute to120-minute that was then mitigated by modifying adjustment software.



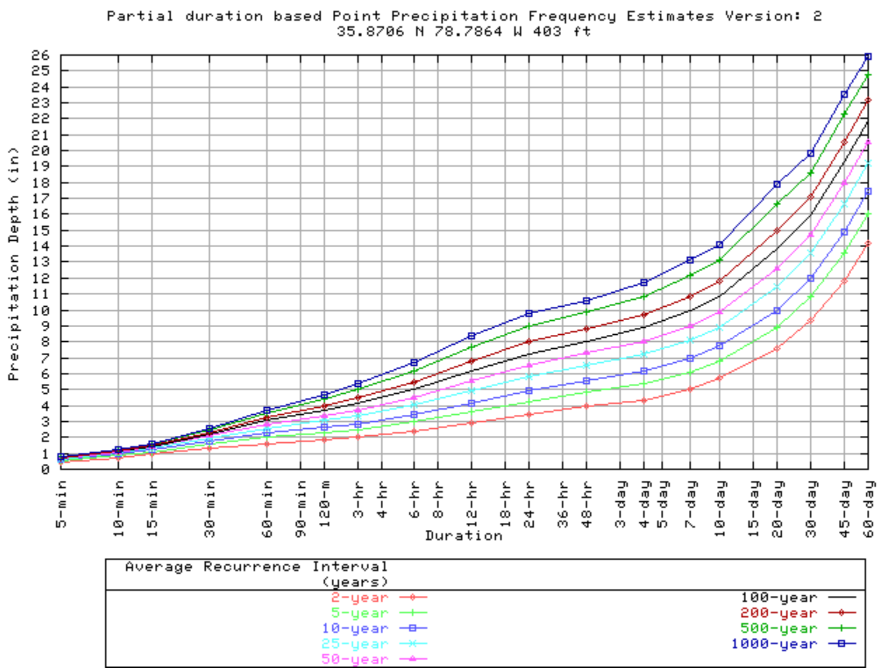
Adjustment software is applied to ensure that hourly-only stations are consistent with nearby co-located hourly/daily stations and thereby reduce bull's eyes in the hourly results. The software adjusts hourly quantiles according to their co-located daily station and/or according to the daily regional characteristics from the 24-hour quantile through to the 2-hour quantile. Specifically, the 24-hour through 2-hour quantiles for hourly stations that are co-located with a daily station are adjusted using station-specific ratios of the station daily and hourly 24-hour means and ratios of the daily and hourly 24-hour regional growth factors (RGFs) at all frequencies (2-yr, 5-yr, …, 1,000-yr). The 24-hour through 2-hour quantiles for hourly-only stations are adjusted using a regionally averaged ratio of the 24-hour mean ratios from all co-located stations within the hourly region and a set of regionally averaged RGF ratios, which are normally less than the station-specific ratios. The 60-minute quantiles for both co-located and hourly-only stations are adjusted by the regional average mean ratio and the regional average RGF ratios (*note: this is a correction to the process as it was erroneously reported in the 18th Progress Report). This adjustment is reasonable and worked well in mitigating the 60-minute bull's eyes. However, a slope discontinuity at the 60-minute quantile was observed at a few stations as a result of this adjustment.

Most of the cases where the slope discontinuities occurred were at co-located stations or daily-only stations next to these co-located stations. At these stations the ratio of RGFs (i.e., daily 100-year 24-hour RGF)/hourly 100-year 24-hour RGF) is less than 1.0 which adjusts the 24-hour through 2-hour quantiles lower. The 60-minute is then adjusted by the regional average RGF ratio which is greater than 1.0 thus increasing the

60-minute quantiles. This created the flat slope observed in the hourly quantiles, particularly in the 1,000-year, that was inconsistent with the slope produced by applying the n-minute ratios to the 60-minute quantiles after spatially interpolating.

To mitigate this artifact, the adjustment software was modified to identify cases where the ratios of daily region RGF versus hourly region RGF are less than 1.0. In these cases, the co-located (i.e., station-specific) adjustment ratios rather than the regional average ratios are applied from 24-hour through 60-minute to maintain consistency over all hourly durations. (See Section 3.4, Software Updates, for more information.) This modification to the adjustment software successfully mitigated the slope discontinuity at all affected stations. Figure 6 shows the final results for Raleigh, NC after the modification was applied. The final results may not be as spatially smooth as the previous results, but it was decided to keep the software modification since it mitigates artifacts that were introduced as part of the process, whereas spatial bull's eyes are artifacts of the station data sample.

Figure 6: Raleigh Durham WSFO AP, NC (31-7069) after mitigation of slope discontinuity between 30-minute to 60-minute and 60-minute to120-minute.



Case 6. A steep gradient causing a bull's eye in the upper-limit confidence maps was observed in southern Indiana between the stations in hourly region 17 and its surrounding region 18. Since hourly region 17 has only 4 stations, the range of confidence limits is larger which contributed to the bull's eye. However, the precipitation frequency curves in region 17, Columbus Water Works, IN (12-1752) for example (see Figure 7), showed the PF estimates "plateau"-ing between 24-hour and 7-day, which indicated that the <48-hr data, which is derived from the hourly data at this station, could have been too high in comparison to the ≥48-hr data, which is derived from the spatially

interpolated daily data. As before, a plateau can result if the spatial consistency adjustment of 1% is applied to several durations to mitigate the differences caused by the 48-hour estimate being greater than the spatially interpolated 4-day estimate and 7-day estimates.

To preserve the spatial detail of the hourly data but mitigate the artifact in the precipitation frequency curve between the hourly and daily durations, it was decided to pursue re-regionalization in this case. Hourly region 17 consists of 4 hourly stations and is contained within hourly region 18, which has 107 stations. Region 17 was expanded slightly to the northwest along the track of mesoscale systems that may come through that area by adding 18 stations from region 18. 100-year 60-minute quantiles in region 17 decreased 15.3%. Stations added from region 18 increased 10.9%. Stations in region 18 decreased 0.4%. This created smoother spatial results, smoothed through the durations (which mitigated the "plateau"-ing between 24-hour and 7-day), added stability to the confidence limits (which will mitigate the bull's eye in the upper limit map), and also retained some of the heavy precipitation detail in the area. Figure 8 shows the final results at Columbus Water Works after the mitigation measures.

Figure 7: Example of artifact at Columbus Water Works, IN caused by internal consistency issues between spatially interpolated results and calculated results.

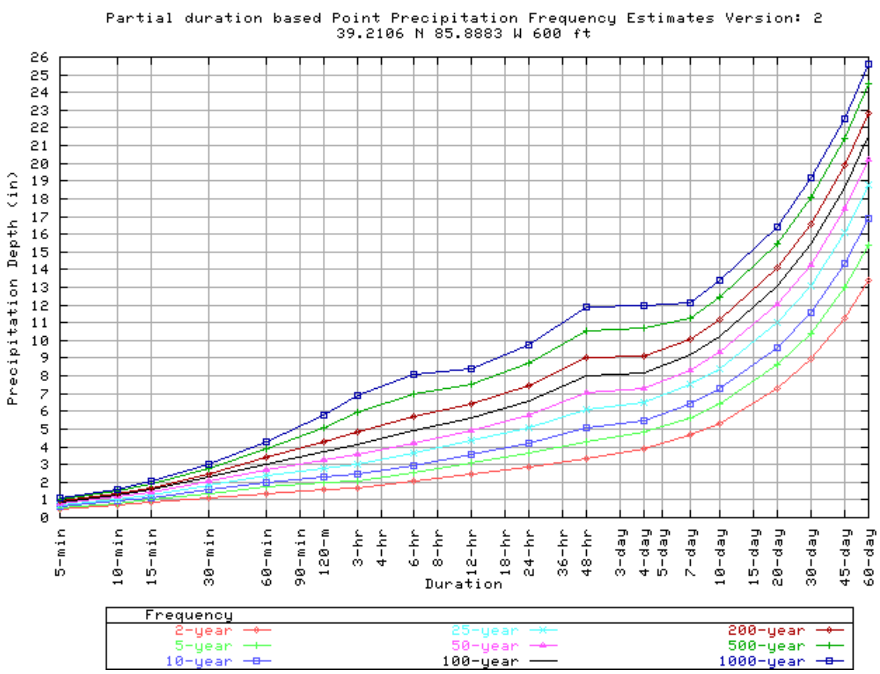
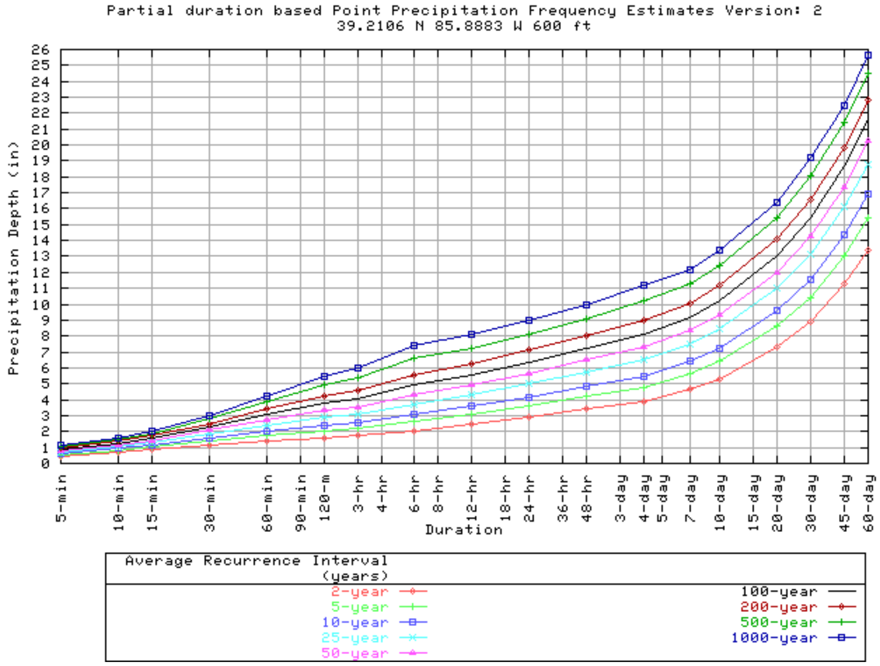


Figure 8: Columbus Water Works, IN after mitigation measures.



Case 7. At-site station, Galva, IL (11-3335), was re-visited since it showed strong differences with the surrounding area, particularly in the upper and lower limits for the 10-day duration. After a thorough investigation, it was decided to merge 11-3335 into daily region 65. 100-year 24-hour estimates at 11-3335 decreased from 7.21” to 6.8" and the 1-day max observed of 10.38" did not exceed 1,000-year return interval. And the gradient with the 24hr at nearby stations in region 67 is reasonable (nearby 11-4710 has 100yr of 6.57" and 1000yr of 8.80"). This added stability to the confidence limits and reduced the bull’s eyes in the 1,000-year maps.

Case 8. Daily region 59 in southwestern Indiana was elevated when spatially compared to the surrounding area, particularly at the 10-day duration. Region 59 has only 3 stations and used the GLO distribution. Expanding the region into region 60 was considered but did not achieve the expected climatological pattern. It was decided to keep region 59 as it is and use the GEV distribution to preserve the spatial detail, which was not climatologically unreasonable, and mitigates the bull’s eye effect for all durations. GEV was selected after a thorough investigation including sensitivity testing and consideration of consistency in the area, particularly since GLO was not most appropriate for all durations. This resulted in a decrease of 3.4% in the 100-year 24-hour and 3.5% in the 100-year 10-day quantiles in region 59.

3.4 AMS-PDS Conversion Factors

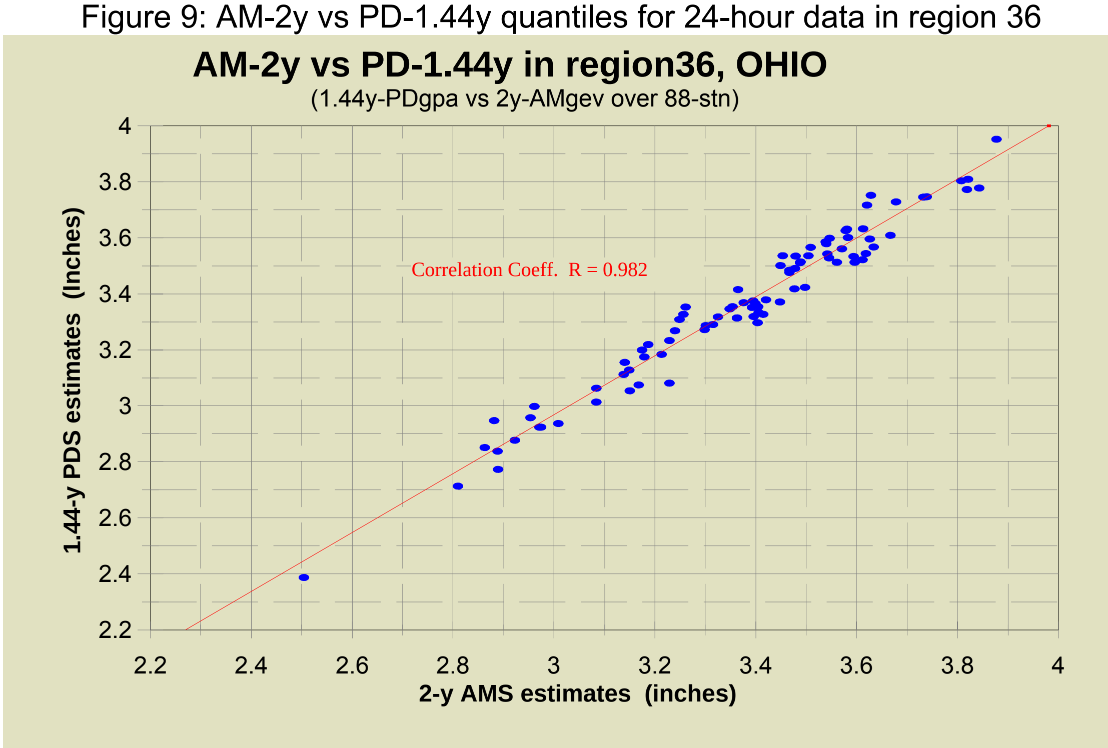
Precipitation frequency results were calculated using annual maximum series (AMS) data. Conversion factors from AMS to partial duration series (PDS) results have been calculated and applied to the results. To derive the AMS to PDS ratios, regional data only (no at-sites) were used. The best-fitting distributions for each individual region for the PDS computations were used. The resulting ratios (Table 1) are consistent with recently calculated Semiarid ratios (NOAA Atlas 14 Volume 1), Technical Paper 40 and theoretical computations. An asymptote of 1.004 was applied for 25-year and longer return periods to generate a smooth consistent curve.

The difference in the 2-year ratios between the Semiarid (1.113) and Ohio (1.086) Projects was investigated. Theoretically, the 2-year AMS quantiles should be equivalent to the 1.44-year PDS quantiles. A plot of the 2-year 24-hour estimates versus the calculated 1.44-year 24-hour estimates (e.g., Figure 9) shows this to be true (correlation=0.982) for the results in the Ohio Project using the ratio 1.086. This demonstrates the reliability of the results.

Table 1: Final AMS to PDS ratios determined for the Semiarid and Ohio Projects.

Project	**2yr**	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**200yr**	**500yr**	**1000yr**
Semiarid	1.113	1.029	1.013	1.006	1.004	1.004	1.004	1.004	1.004
Ohio	1.086	1.023	1.010	1.004	1.004	1.004	1.004	1.004	1.004

Figure 9: AM-2y vs PD-1.44y quantiles for 24-hour data in region 36



3.5 Software Updates

Hourly confidence limit software was modified to accommodate recent changes that ensure consistency between hourly-only stations and nearby co-located hourly/daily stations and thereby reduce bull's eyes in the hourly results. The software adjusts hourly confidence limits according to their co-located daily station and/or according to the daily regional characteristics from the 24-hour quantile through to the 2-hour quantile:

1. The site-specific co-located adjustment is applied to the co-located stations using ratios of the 24-hour station means and ratios of the daily and hourly regional growth factors (RGFs) for durations 24-hour down to 2-hour.
2. Hourly-only stations are adjusted using a regionally averaged ratio of the daily and hourly RGFs for all co-located stations within the hourly region for durations from 24-hour down to 2-hour.
3. 60-minute quantiles for both co-located and hour-only stations are adjusted using the regionally averaged adjustment ratios.

Software that adjusts quantiles for the co-location of daily and hourly data was modified to identify cases where the ratios of daily region 100-year 24-hour RGF versus hourly region 100-year 24-hour RGF are less than 1.0 (see Section 3.3 Final review and modifications, Case 4 for additional details). The RGF ratios are based on each return interval, but the 100-year interval was used as the flag. In all identified cases, the co-located (i.e., station-specific) adjustment ratios rather than the regionally averaged ratios are applied from 24-hour through 60-minute to maintain consistency over all hourly durations. A comparable modification was made to the confidence limit software.

3.6 Spatial Interpolation

3.6.1 Grids

SCAS delivered the final grids (Table 2) to HDSC on May 24, 2004. As a reminder, the Ohio River Basin and Surrounding States mean annual maximum grids were created by using a strong local relationship between the mean and the square-root of PRISM's 1971-2000 mean annual precipitation. The PRISM-produced mean annual maximum grids provide the basis for deriving the precipitation frequency grids. See past Progress Reports for more details.

Table 2: Mean annual maximum grids interpolated by PRISM.

Duration
60-minute
120-minute
3-hour
6-hour
12-hour
24-hour
48-hour
4-day
7-day
10-day
20-day
30-day
45-day
60-day
14 grids total

The Cascade Residual Add-back (CRAB) grid derivation process was used to create the entire suite of precipitation frequency grids (see CRAB description in 12th Ohio River Basin & Surrounding States Progress Report, Section 4.3). Several iterations of CRAB were run to allow evaluation and modification to the resulting grids/maps.

During this process, it was determined that the PRISM mean annual maximum grids were too low in/around the Chesapeake Bay. This was being caused by low mean annual precipitation coupled with limited data density. After evaluating other data sources and discussing the dynamics of short-duration precipitation events with the Maryland State Climatology office, it was decided to adjust the hourly PRISM-produced mean annual maximum grid cell values upward about 10 percent in the Chesapeake Bay for durations 60-minutes through 12-hours. This mitigated the unnatural low bull's eye in the precipitation frequency estimates.

In late June 2004, a final CRAB run was conducted and the final grids evaluated one last time before publication on June 29, 2004.

3.6.2 Spatial Smoothing Algorithm

An advanced spatial smoothing algorithm was developed to mitigate climatologically unnatural variability in the spatially distributed precipitation frequency estimates. The algorithm smoothes estimates in areas with flat terrain and similar climates, but retains patterns in complex terrain where more variability is expected and appropriate. The degree of spatial smoothing applied to a grid cell is dictated by its surrounding terrain and proximity to a coastline. In areas where terrain or the proximity of the coastline is important in defining patterns of precipitation, less spatial smoothing was applied.

To gauge the effectiveness of terrain to influence the precipitation frequency estimates, PRISM's effective terrain height grid was used. The effective terrain height grid, developed by Chris Daly of the Spatial Climate Analysis Service, is based on a 2.5-minute digital elevation model (DEM) in meters. It was prepared by finding the minimum elevation within a 40-km radius of each grid cell, then spatially averaging the minimum elevations to produce a smooth, base elevation grid. Then, to obtain the effective terrain height grid, the based grid was subtracted from the original DEM grid and filtered to produce a smooth grid, which has units of meters. For more details, please refer to http://www.ocs.orst.edu/pub/prism/docs/effectiveterrain-daly.pdf.

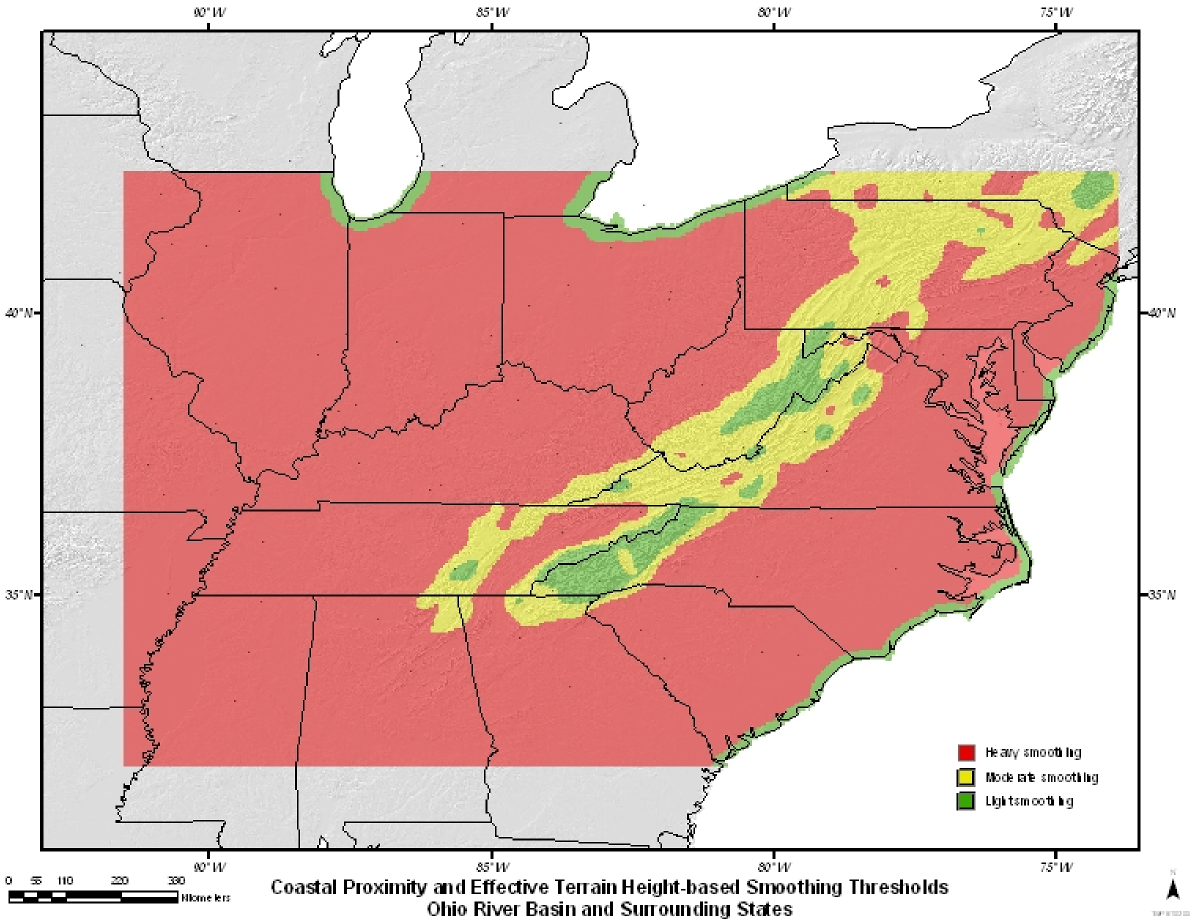
In our process, the effective terrain height grid was smoothed further to prevent discontinuities at the boundaries of different degrees of spatial smoothing. It was spatially averaged over a 40-km radius of each grid cell.

To gauge the impact of precipitation frequency estimate patterns as a result of coastal influences, PRISM's coastal proximity grid was used. The coastal proximity grid, also produced by Chris Daly, is composed of grid cell values denoting a measure of the shortest distance from a cell to the water. In other words, it is the distance to the nearest ocean pixel, divided into 10 distance classes. The coastline is defined as being outside the mask used for PRISM mapping, which means that the Chesapeake Bay, for example, is not ocean. For more details, visit:
http://www.ocs.orst.edu/pub/prism/docs/prisguid.pdf.

Based on the effective terrain height and coastal proximity grids, HDSC developed three degrees of initial spatial smoothing: heavy, moderate and none. The map below indicates the areas receiving the different degrees of smoothing.

1. HEAVY: Flat areas are determined if effective terrain height is less than 100 m (328 ft), and then a 17x17 (approximately 15 miles by 15 miles) grid cell, center-weighted filter is used at the longer durations and a 25x25 (approximately 25 miles by 25 miles) filter at the shorter (<24-hour) durations. The shorter durations were subjected to greater smoothing since the lower station density is prone to cause unnatural variability.
2. MODERATE: Moderately complex terrain are determined if effective terrain height is greater than 100 m (328 ft) and less than 200 m (656 ft), and then a 11x11 (approximately 5.5 miles x 5.5 miles) grid cell, center weighted filter is used for all durations.
3. NONE: Complex terrain or along coastlines are determined if effective terrain height is greater than 200 m (656 ft) or if the coastal proximity grid (a grid of values indicating distance from coast) is <=5, and then no filter is used for this stage.

Map 1. A map of areas receiving different degrees of spatial smoothing based on PRISM's effective terrain height and coastal proximity grids.



Once the above filtering is complete, a final 5x5 (approximately 2.5 mile by 2.5 mile) grid cell, center-weighted filter is applied to the entire grid to blend the smoothing threshold boundaries, lightly filter the coastlines and complex terrain, remove extraneous "noise" in the spatial interpolation and promote smooth contour lines when interpolated.

3.6.3 N-minute ratios

A sub-routine was written to generate n-minute ratio grids using the two n-minute regions, northern and southern. To re-cap, each duration, frequency and region has its own unique n-minute ratio that is applied to the appropriate 60-minute grid to compute the n-minute precipitation frequency estimates. Table 3 shows the n-minute ratios for the northern and table 4 shows the n-minute ratios for the southern region.

For each frequency and duration, the north and south ratio was applied to a grid of the north and south regions. At the boundary, the grid cells were subjected to spatial averaging for a distance of approximately 90 miles, thereby providing a wide band of gradually changing ratios from north to south. In a subsequent sub-routine, these grids are multiplied by the appropriate 60-minute grid to create the n-minute precipitation frequency grids.

Table 3: N-minute ratios for Ohio project area – northern region.

Frequencies	**5-min**	**10-min**	**15-min**	**30-min**
2-year	0.319	0.498	0.609	0.815
5-year	0.305	0.474	0.582	0.797
10-year	0.298	0.460	0.566	0.786
25-year	0.289	0.442	0.546	0.771
50-year	0.283	0.429	0.531	0.759
100-year	0.277	0.417	0.518	0.748
200-year	0.272	0.406	0.505	0.737
500-year	0.266	0.391	0.488	0.723
1000-year	0.261	0.380	0.475	0.712

Table 4: N-minute ratios for Ohio project area –southern region.

Frequencies	**5-min**	**10-min**	**15-min**	**30-min**
2-year	0.287	0.459	0.577	0.797
5-year	0.271	0.434	0.549	0.780
10-year	0.262	0.419	0.530	0.768
25-year	0.251	0.400	0.507	0.751
50-year	0.243	0.387	0.490	0.738
100-year	0.236	0.375	0.474	0.726
200-year	0.229	0.363	0.458	0.713
500-year	0.220	0.348	0.438	0.697
1000-year	0.214	0.337	0.423	0.685

3.6.4 Pseudo data

In order to create climatologically sound short duration (<24-hour) precipitation frequency patterns in data void/limited areas, pseudo hourly stations were added to the mapping dataset at existing daily-only stations. Hourly pseudo data were also used to mitigate inconsistencies between the daily and hourly precipitation frequency estimates. Inconsistencies arose at daily-only stations where the differences between the 12-hour spatially interpolated precipitation frequency estimates were much lower than the 24-hour data at the station. There were 21 cases where inconsistencies arose at daily-only station locations and caused an unrealistic jump in the precipitation frequency estimates from 12-hours to 24-hours at those locations (see table 5). Pseudo data were generated for these locations.

Table 5. Hourly pseudo stations in the Ohio River Basin and Surrounding States project.

Station ID	Name	State
11-0338	AURORA COLLEGE	IL
11-2223	DE KALB	IL
11-4530	JOLIET BRANDON RD DAM	IL
11-4535	JOLIET	IL
11-7354	ROCHELLE	IL
11-9221	WHEATON 3 SE	IL
12-4662	KOKOMO POST OFFICE	IN
12-5174	LOWELL	IN
18-6620	OAKLAND 1 SE	MD
28-0690	BELLEPLAIN	NJ
31-0184	ANDREWS	NC
31-0241	ARCOLA	NC
31-6031	NANTAHALA	NC
31-6044	NASHVILLE	NC
31-6135	NEW HOLLAND	NC
38-0972	BRANCHVILLE 6 S	SC
38-5628	MCCLELLANVILLE	SC
38-7313	RIMINI	SC
44-0385	BACK BAY WILDLIFE REFU	VA
44-0993	BREMO BLUFF PWR	VA
44-6456	OYSTER 1 W	VA

The creation of pseudo hourly precipitation frequency estimates was similar to the approach used to alleviate 12-hour to 24-hour jumps at co-located stations. The pseudo precipitation frequency estimates were generated by applying a ratio of x-hour estimates to 24-hour estimates that was spatially interpolated (using inverse distance weighting) based on only co-located stations. The ratio at each co-located station was calculated using the station's 24-hour precipitation frequency estimate to its x-hour precipitation frequency estimate and spatially interpolated. The appropriate ratio was then applied to the daily-only 24-hour precipitation frequency estimates to generate the pseudo hourly data. The mitigation provided a smoother, more meteorologically-sound transition from hourly to daily precipitation frequency estimates.

As validation of the process, tests showed that creating pseudo data for daily-only stations that did not exhibit a large difference from 12-hour to 24-hour resulted in nearly identical precipitation frequency estimates before and after the inclusion of pseudo data. Pseudo data were not added to stations that did not need it or at ungauged locations. Locations where a jump between 12-hour and 24-hour estimates could not be expressly proved or was assumed accurate based on climate were not mitigated. Pseudo data were used only where deemed absolutely necessary to produce consistent results.

3.7 Precipitation Frequency Data Server

The Precipitation Frequency Data Server (PFDS) under went several subtle, but important changes. They include:

1. In order to be consistent and clear, we have adopted the standard terminology proposed by The Institution of Engineers, Australia in the 1987 edition of Australian Rainfall and Runoff for describing precipitation frequency estimates. Therefore, the PFDS output pages now indicate the frequency when using a partial duration series as Average Recurrence Interval (ARI) in units of years. Likewise, the output indicates frequency when using an annual maximum series as Annual Exceedance Probability (AEP) in units of 1 in Y, where Y is dimensionless; for instance, a 100-year frequency is indicated as “1 in 100,” in other words there is a 1 in 100 chance of it being exceeded in any particular year.
2. The text describing the seasonality graphs, which are still under construction for the Ohio River Basin and Surrounding States, was changed to be consistent with the new terminology.
3. The map of the United States on the opening screen of the PFDS, was changed to reflect the areas that have updated precipitation frequency estimates available.

On June 29, 2004, the PFDS was populated with the final Ohio River Basin and Surrounding States precipitation frequency estimates. Not only were final point estimates made available via the point-and-click interface, but also the ArcInfo ASCII grids, shapefiles, and all associated metadata. The official release of these data involved the modification of several of the PFDS web pages to allow users to download the variety of data available, which include: time series (annual maximum and partial duration), station lists (hourly and daily), and metadata (grids and shapefile).

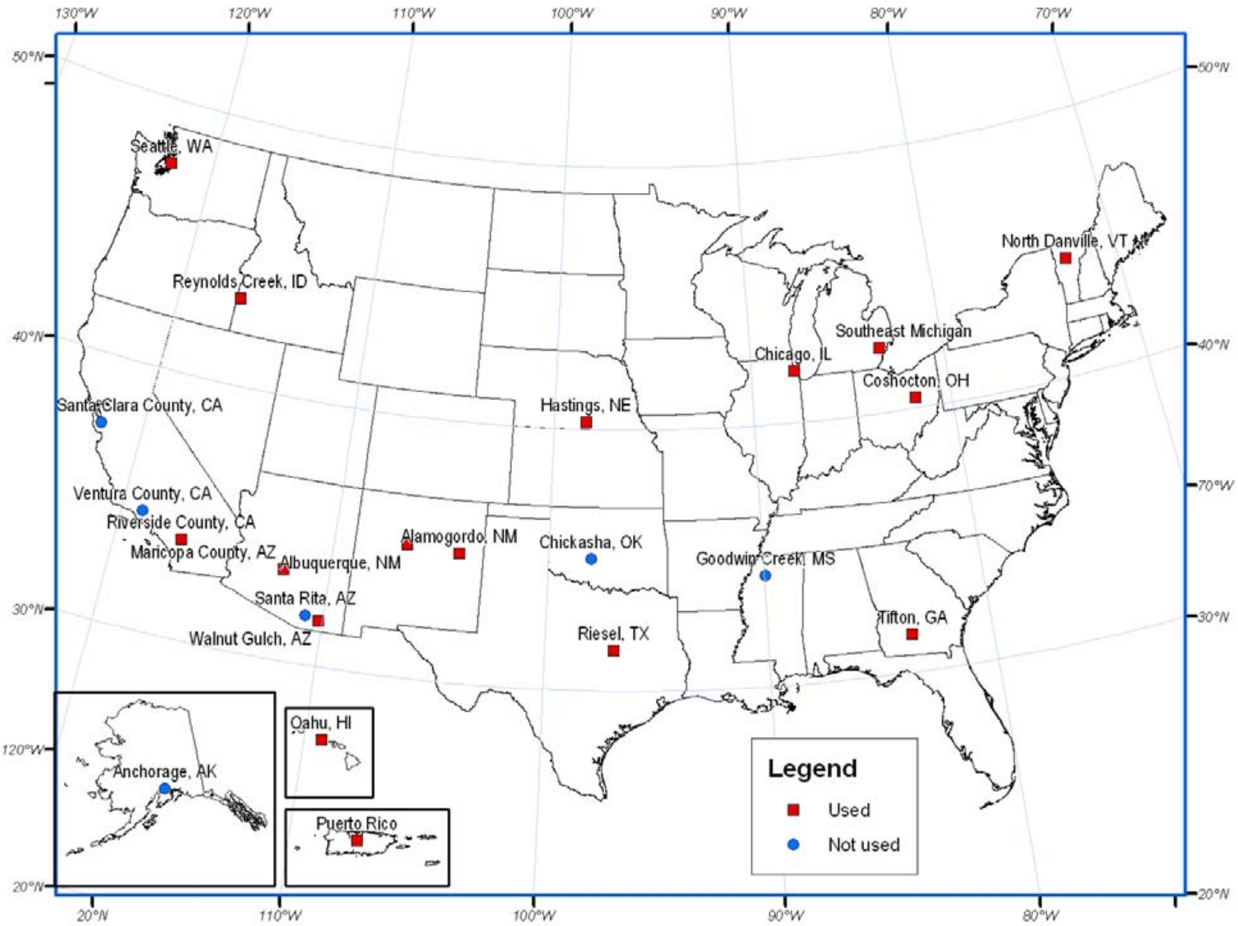
3.8 Areal Reduction Factors

Progress continues in the development of geographically-fixed Areal-Reduction-Factor (ARF) curves for area sizes of 10 to 400 square miles. Development and testing of software from the procedure described in NOAA Technical Report NWS 24 (TR-24) is still underway. A preliminary set of ARF curves for the 2-year return period for the Chicago, IL area study site are consistent with results published in TR-24.

A total of 15 study areas throughout the United States will be used in the study (see Figure 10). The “not used” study areas indicated in Figure 10 were considered but judged inadequate for the study due to poor data, limited or no metadata, or other problems. The set of ARF curves developed for each study area used will be tested for differences to determine if a single set of ARF curves can be used for the entire U.S. as is the case today or whether separate curves for different regions of the country are more appropriate.

Quality control has been performed and completed on the precipitation data from the sites in the southeast Michigan, Albuquerque, and Seattle study areas. A new site, Clark County, NV, has been identified and will be shortly added to the current list of sites to be used in the A-R-F curve development. There are currently 14 sites located throughout the conterminous US, Hawaii, and Puerto Rico that have been quality controlled, processed and ready for ARF analysis.

Figure 10: Map of ARF study areas



4. Issues

4.1 Recent and Upcoming Presentations

Past and future presentations by HDSC, include the following:

- “Statistics of Recent Updates to NOAA/NWS Rainfall Frequency Atlases” at the American Society of Civil Engineers World Water and Environmental Resources Congress on June 29, 2004
- “Recent Updates to NOAA/NWS Rainfall Frequency Atlases” at the California Extreme Precipitation Symposium in Davis, CA on July 1, 2004
- An update of the Ohio River Basin and Surrounding States Precipitation Frequency Project progress at the 84th Meeting of the Ohio River Basin Commission on July 14, 2004
- “Regional Frequency Studies of Annual Extreme Precipitation in the United States Using Regional L-moments Analysis” at the International Ocean-Atmosphere Conference held by the Chinese-American Oceanic and Atmospheric Association (COAA) in Beijing, China on June 27-30, 2004

5. Projected Schedule and Remaining Tasks

The following list provides a tentative schedule with completion dates. Brief descriptions of tasks being worked on next quarter are also included in this section.

Precipitation Frequency Maps [August 2004]
Final Documentation [August 2004]
Spatial Relations (Areal Reduction Factors) [August 2004]

5.1 Precipitation Frequency Maps

Cartographic maps will be produced and published on-line as Adobe PDF files during the next quarter.

5.2 Final Documentation

Final documentation is currently being written for the Semiarid Project. During the next quarter, this text will be modified to reflect the Ohio Project.

5.3 Areal Reduction Factors (ARF)

Computations for the ARF curves will be completed in the next quarter for 15 areas. The resulting curves will be tested for differences to determine if a single set of ARF curves is applicable to the entire U.S. or whether curves vary by region.

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